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Increasing cotton seed fibre density as a breeding strategy to improve fibre fineness

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ABSTRACT

Cotton breeders have long faced the challenge of simultaneously improving yield and fibre quality. Spinners demand better quality, but until price premiums increase to compensate producers, yield will always be the economic prize. Therefore, yield must at least be maintained when improving fibre quality for a cultivar to remain competitive. This study explores the use of a yield component, seed fibre density (FD) as a means for providing yield stability while improving fibre fineness (lower linear density) and tests the usefulness of increasing FD as a way of ensuring micronaire is not too high. Three breeding populations were created by crossing high by high FD lines and two separate high by low FD lines. These populations were evaluated in single plant selection (SPS), progeny row and advancement of the highest and lowest FD lines across populations to a replicated experiment. Results indicate narrow sense heritability of FD was 0.25 in early generations, although not as high as that for lint fraction, length, short fibre index and elongation. A 19% increase in FD resulted in a 14 $\mu g\,m^{-1}$ decrease in fineness without affecting yield. There were negative associations between FD with length, uniformity, short fibre index and strength. Four other populations were created by crossing high and low FD breeding lines with high micronaire lines (>4.5), to evaluate the usefulness of FD for improving (reducing) fineness and micronaire. Data from these populations indicated FD was an effective way to decrease fineness and micronaire while maintaining yield. It was concluded that although FD was a practical trait to use in breeding to modify fibre fineness, breeding populations must be segregating for both fineness and FD and careful attention must be given to appropriate parental choice and population size to avoid reductions in fibre length and strength as a consequence of increasing FD.

1. Introduction

Advances in textile manufacturing have increased demands on the physical properties of cotton. Fibre quality is held to high international standards but the financial premiums for producing such quality have not stimulated better fibre quality cultivars. This accentuates the long standing challenge for cotton breeders to produce premium fibre quality while simultaneously maintaining yield.

Early cotton research has determined that yield and fibre quality properties have strong negative associations due to genetic linkage, pleiotropy or various physiological reasons (Meredith, 1984). Clement et al. (2012) reported that these negative associations still exist in current genotypes, with fibre strength having the strongest association followed by fibre length then fineness. It is not surprising that these three fibre properties are in high demand by spinners; all contributing to yarn tenacity (Meredith et al., 1991)which ultimately affects production speed, yarn and overall fabric quality.

Cotton fibre quality is based primarily on parameters of length, strength and micronaire. Producers receive small premiums for these traits that are above a base standard while spinners purchase cotton based on these measurements. Micronaire values less than 3.5 indicate immature fibres that are prone to break, dye poorly and create fibre entanglements (neps) that affect fabric appearance (Han et al., 1998). Micronaire values greater than 5.0 imply coarse fibres which cannot produce fine yarn. Micronaire is not the best measure of cotton fibre fineness as it is a product of the fibre maturity (secondary wall thickening) and linear density (Lord, 1961). In Australia, 53% of the cotton crop in 2006 had micronaire values greater than 4.6 (Australian Cotton Shippers Association, ACSA). This was above the Australian base grade for micronaire (3.8–4.5)

Abbreviations: AFIS, Advanced fiber Information System; CSIRO, Commonwealth Scientific and Industrial Research Organization; FD, Fibre Density; FMT, Fibre Maturity Tester; FPS, Fibres Per Seed; HVI, High Volume Instrument; LF, Lint Fraction; SFI, Short Fibre Index; SPS, Single Plant Selection.

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and there were occasions when micronaire above 5.0 led to price discounts unacceptable to growers. Factors involved include hot and dry conditions and management for high yield. Fibres developing under high temperatures are prone to higher micronaire values (Bradow et al., 1996; Bange et al., 2010). Breeding efforts in Australia have been partially successful in lowering the micronaire, only 24% was greater than 4.6 in 2012 (ACSA, 2013), however high micronaire discounts still occur under suitable conditions, so there is a role for breeding to continue reducing the genetic component of high micronaire.

Finer fibres allow more fibres per cross section of yarn, improving yarn tenacity and delivering a finer yarn for high end garments (Deussen, 1992). A number of studies have shown a strong positive association between fineness (often reported as micronaire) and yield – where higher yield has undesirable coarse fibre (Meredith, 1984). Basically, if all yield components were held constant, selecting for finer fibre during breeding would result in lower yield. Improving the yield component fibres per seed (FPS) and seed fibre density (FD) (Worley et al., 1976; Smith and Coyle, 1997) may allow for finer fibres and yield stability. FPS is the number of individual fibres on a seed coat whereas FD is FPS adjusted for seed size or seed surface area. Liu et al. (2011) have shown that FPS has a heritability of 0.40 but negative associations between micronaire and FPS were shown by Smith and Coyle (1997). Rahman (2006) suggested that selection for high fibres per seed was advisable for increasing fineness. Thus, in development of breeding populations for improved fineness, it is desirable to have diversity in the parents for FPS as well as fineness.

Since there are now suitable instruments to separately measure fibre fineness and maturity (FMT (Montalvo and Hoven, 2005) AFIS (Bradow et al., 1996) Cottonscope (Rodgers et al., 2012), these can be applied in breeding to ensure the optimised balance of fibre fineness and maturity can be selected. The aims of this series of experiment were to determine the variability among genotypes for FD, to determine the heritability in breeding populations and to demonstrate the utility of that trait in maintaining yield while improving fineness and subsequently decrease micronaire.

2. Materials and methods

2.1. Generic field information

All experiments were conducted at the Australian Cotton Research Institute (ACRI), Narrabri, NSW, from 2006 to 2012. The soil type is a grey clay with heavy texture, classified as Ug 5.2 (Isbell, 1996) US classification is Typic Haplustert (USDA, 2010). All experiments were sown in early to mid October in rows 100 cm apart aiming at 10 plants per metre of row. Crops were managed with full irrigation, spraying for pests as required and weed management by pre-planting herbicides such as trifluralin and fluorometuron followed by inter-row cultivation prior to flowering. Replicated experiments consisted of four replications, three row plots x 14 metres with the centre row used for machine harvesting at maturity.

A 250 g subsample was taken for determining lint fraction (LF) on a 20-saw gin, fibre quality tested on a HVI 1000 (USTER® Technologies Inc., Charlotte, NC) with fineness and maturity ratio measured on a Shirley Fineness Maturity Tester (FMT-3) (Shirley Developments Ltd., Stockport, England). Fuzzy seed index was determined by the weight of 100 seeds. FPS was estimated by dividing the weight of lint on one seed by the average weight of one fibre (HVI upper half mean length multiplied by length uniformity by FMT fineness). The seed surface area (SSA) was calculated by the equation ($35.74 + 6.59 \times$ fuzzy seed index) (Groves and Bourland, 2010). The estimated FPS was then divided by SSA to calculate FD. An in-depth detail of FPS and FD calculations are reported by Clement et al. (2014).

2.2. FPS diversity/populations

A preliminary replicated experiment was planted in 2006 to determine the range of diversity in FPS within the CSIRO cotton breeding program collection, consisting of 36 breeding lines, 7 local commercial cultivars and 7 various international genotypes. Data demonstrated significant diversity for FPS and two sets of sister breeding lines were identified with contrasting FPS: CSX2194 and CSX2590 had FPS of 14,932 and 19,525, respectively; CSX4365 and CSX4252 had 15,018 and 18,050, respectively (Table 1). Three populations involving high by high FPS (67201 = CSX2590 × CSX4252) and two high by low FPS (67202 = CSX2590 × CSX2194 and 67203 = CSX4252 × CSX4365), were formed in 2007. Crosses between sister lines were done to enable assessment of the inheritance of FPS between related lines. F_3's were planted as single plant selections (SPS) in 2009. The SPS consisted of 216 plants per population and were advanced to F_4 progeny rows in 2010. It was determined at this point and time that FD was a more accurate measure than FPS and was used for selection criteria and crossing. Therefore, the highest 20 FD F_5 lines and lowest 20 FD lines across populations were tested in a replicated experiment in 2011.

2.3. Utility of FD

A second experiment was conducted to determine the utility of FD in maintaining yield while simultaneously improving fineness. Contrasting FD sister lines, CSX2194 and CSX2590, were crossed with two high micronaire (>4.5) lines CSX5264 and CSX3369 to form four populations. These lines were chosen because their pedigree which are prone to high micronaire, such as Sicot 72 and CSX1303. The high FD parent populations were 10227 (CSX2590 × CSX5264) and 10228 (CSX2590 × CSX3369), while the low FD parent generated populations 10229 (CSX2194 × CSX5264) and 10230 (CSX2194 × CSX3369). These crosses were performed in the glasshouse; seed from single F_2 plants were planted in the field as F_3 progeny rows in 2010 with 48 lines per population.

2.4. Statistical analyses

In the SPS, three populations were tested in the same experiment. Unreplicated F_4 progeny rows were arranged in an augmented design with (Kempton and Gleeson, 1997) commercial checks placed one in six plots within the experiment (17.3% checks). Replicated experiments were grown in a Latinized alpha design (Williams, 1986) with Siokra 24 (Stiller and Reid, 2005) and Sicot 71 (Reid, 2003) as commercial checks. These experiments were analysed with spatial models using ASREML-R software (Butler et al., 2007) with the detail described below: initially the population was fitted as fixed and the individual breeding lines within the population were fitted as random to search appropriate spatial models for the experiments. When the model was determined, the line within the population was refitted as fixed and the best linear unbiased estimates (BLUEs) for individual test lines were obtained. Correlations and partial correlations were analyzed across and within populations and generations for FPS diversity experiments based on the estimates using SAS 9.0 (SAS Institute Inc., 2008).

Narrow sense heritability for individual traits was estimated using parent-offspring regression (Nyquist and Baker, 1991), by taking account of how lines in F_4 progeny row test performed relative to the F_3 SPS generation. The estimation was done for individual families, across families and adjusted by an inbreeding coefficient of self-generation (Nyquist and Baker, 1991). Bootstrap